Secondary electron time detector for mass measurements at CSRe*

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Abstract The Isochronous Mass Spectrometry is a high accurate mass spectrometer. A secondary electrons time detector has been developed and used for mass measurements. Secondary electrons from a thin carbon foil are accelerated by an electric field and deflected 180° by a magnetic field onto a micro-channel plate. The time detector has been tested with alpha particles and a time resolution of 197 ps (FWHM) was obtained in the laboratory. A mass resolution around 8×10^{-6} for $\Delta m/m$ was achieved by using this time detector in a pilot mass measurement experiment.

Key words isochronous mass spectrometry, time of flight, CSRe

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1 Introduction

Mass is a fundamental property of the nucleus. High resolution experimental data are necessary for us to understand astrophysics and nuclear structure. The masses for most of the stable and long-lived isotopes are well known, while experimental data are scarce for exotic nuclides far from the valley of stability [1].

The experimental results from the GSI-ESR prove that the combination of the in-flight separator and the Cooler Storage experimental Ring (CSRe) is an efficient method for direct mass measurements of short-lived exotic nuclides [2]. The recently commissioned CSR at the Institute of Modern Physics (IMP) is a powerful facility for such investigations [3].

For mass measurements in a storage ring, there are two complementary methods in use: the Schottky Mass Spectrometry (SMS) and the Isochronous Mass Spectrometry (IMS) [4]. In SMS the velocity spread of the ions stored in the ring is reduced by electron cooling, so this method is only suitable for nuclides with long half-lives due to the cooling time. While the cooling is not necessary for IMS, it is suitable for mass measurements of exotic nuclei with half-lives of several tens of microseconds.

The Schottky beam diagnosis can be used to obtain the particle revolution frequencies, while it is not feasible for IMS because it requires a little time to reach certain accuracy. The IMS needs a very sensitive and fast detector to determine particle revolution frequencies which depend only on their mass-to-charge ratios. In this context a detector of time of flight was developed.

2 Design of the detector

The basic principle of the time detector is detecting the secondary electrons (SEs) emitted from a thin carbon foil as incident particles pass through it perpendicularly. The energy loss of stored ions in the carbon foil is inevitable, while acceptable, since the energy loss is only $\sim10^{-7}$ per turn in this energy range. There are two methods to guide the SEs: with

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an electrostatic field [5] or with a magnetic field [6]. The method with the electrostatic field is not feasible because the metal grids will cause ion losses. In the second method, the influence of the external magnet is not negligible, which should be compensated with an optical setting of the CSRe. To meet experimental requirements, the properties of good time resolution, high detection efficiency and ultra-high vacuum should be also considered.

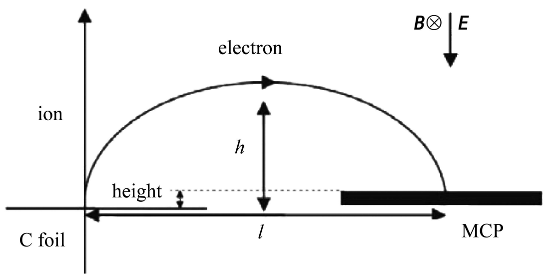


Fig. 1. The schematic of the detector guiding the SEs with magnetic field.

The schematic of the detector guiding the SEs with a magnetic field is shown in Fig. 1. The parameters of the SEs trajectory can be expressed as [6]

$$l = 2\pi mE/eB^2 \,, \tag{1}$$

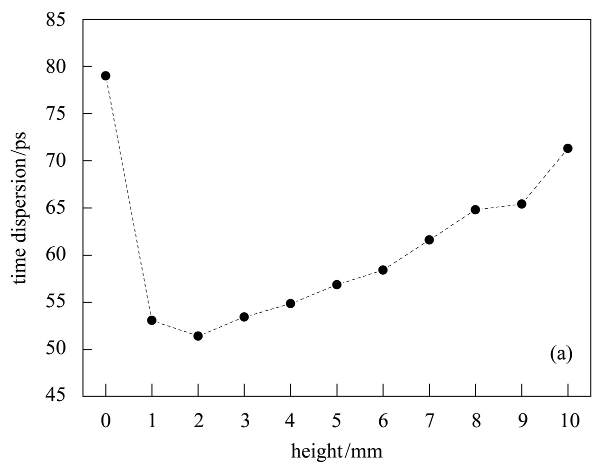
$$h = 2mE/eB^2 \,, \tag{2}$$

$$t = 2\pi m/eB \,, \tag{3}$$

here l is the lateral displacement, h is the amplitude of the cycloid, t is the transition time of the SEs, $\boldsymbol{E}$ is the electrostatic field, $\boldsymbol{B}$ is the magnetic field, m is the electron mass and e is the electron charge.

The SEs emission is a surface effect, the most probable energy is about a few eV and the angular distribution is large [6], which will cause large transition time dispersion. To reduce the effect of the initial energy and angular distribution, the SEs are accelerated to several keV by the electric field. The homogeneous electric field is essential for a good time resolution of the detector, which plays an important role in the isochronous transportation of SEs. To get a homogeneous electric field, the structure of the detector was optimized with a SIMION [7] simulation. Fig. 2(b) shows the final configuration of the time detector. The homogeneous electric field is produced by three potential plates, two carbon foils (one for SEs emission, another one for ions passing by and compensating the electric plate) with a diameter of 40 mm and one MCP with an active diameter of 40 mm. In this structure, $\boldsymbol{E} \approx 120$ V/mm and assuming that the initial velocity of the SEs is a fixed value, a several ps transition time dispersion was obtained from the SIMION simulation, which is mainly caused by the inhomogeneity of the electric field. The magnetic field is produced by an external dipole magnet whose inhomogeneity is less than 1%, which could only account for about 30 ps transition time dispersion.

The transition time dispersion is also related to the height between the SEs emission carbon foil and the MCP (see Fig. 1). It is assumed that the angular distribution of SEs is isotropic in the forward hemisphere and their energy is a few eV [8]. The relation of the transition time dispersion and the height was obtained with the SIMION simulation as $\boldsymbol{E} \approx 120$ V/mm and $\boldsymbol{B} \approx 0.0075$ T, respectively. Fig. 2(a) shows the simulation results.



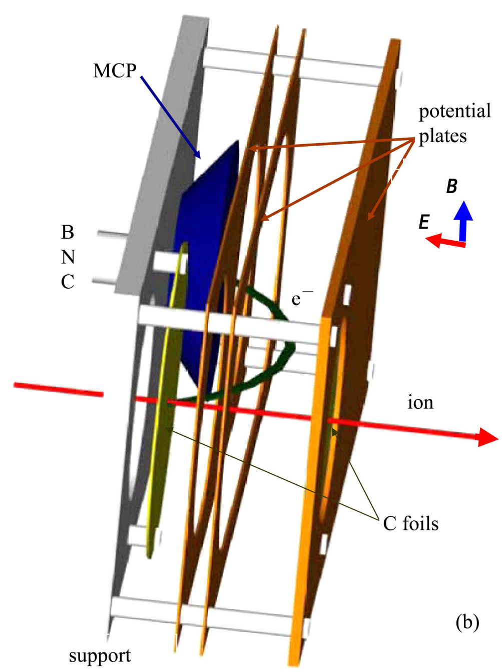


Fig. 2. (a) Dispersion of the transition time as a function of height between the SEs emission carbon foil and the MCP. (b) Schematic view of the detector, which consists of three Potential plates, two carbon foils and a MCP.

As shown in Fig. 2(a), the minimum transition time dispersion occurs for a height of around 2 mm. The time dispersion is consistent with a simple estimation according to the formula (4) [8]

$$\Delta t = \frac{1}{\omega}\frac{\nu(0)}{(E/B)}, \quad (4)$$

where $\omega = qB/m$, $\nu(0) \approx 10^8$ cm/s is the velocity of SEs.

Considering the transition time dispersion, detection efficiency and electric field, a height of 4 mm between the MCP and emitted SEs carbon foil was selected.

The detector will be used in the CSRe with an ultra-high vacuum of 10^{-11} mbar. To meet the requirement of the vacuum and the fact that the device will be baked up to 150 ℃, anaerobic copper, stainless steel and aluminum based ceramics were chosen as materials to construct the detector.

3 Test of the detector

The detector was tested in the laboratory with alpha particles from an ^{241}Am source. The setup is shown in Fig. 3.

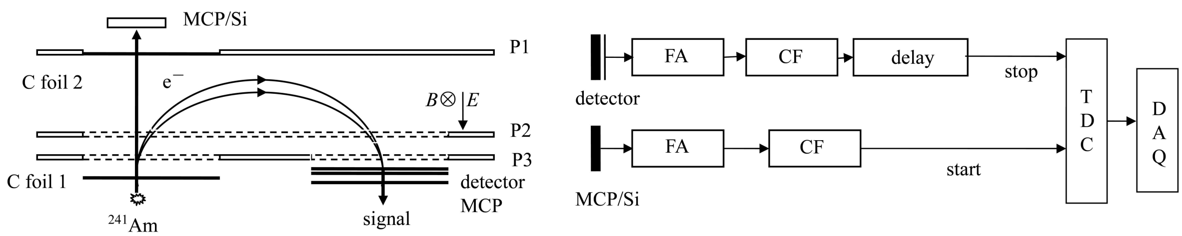


Fig. 3. The test setup of the detector in the laboratory. FA is a fast amplifier, CF is constant fraction.

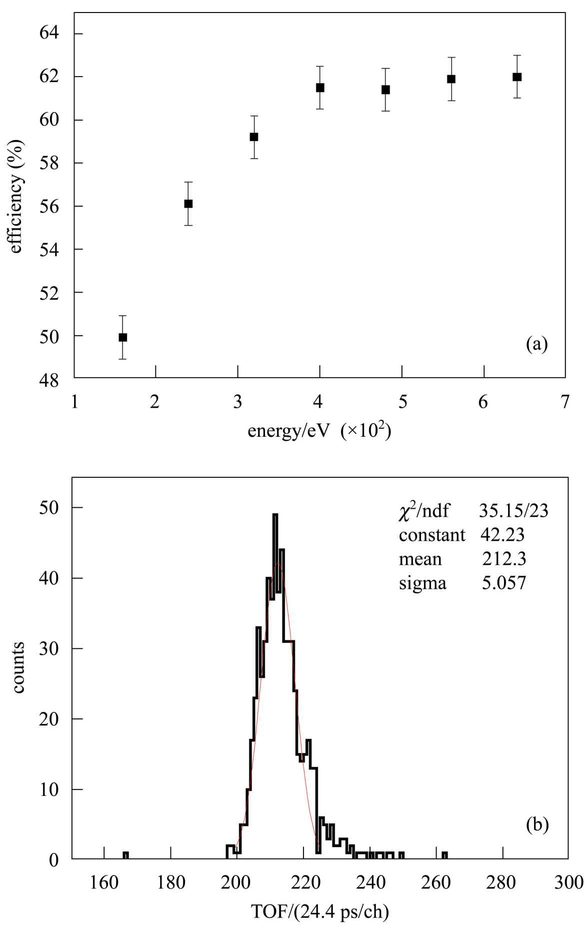


Fig. 4. (a) Detection efficiency as a function of impact energy of electrons. (b) Time resolution of the detector is (197±10) ps.

3.1 Efficiency

The detection efficiency was tested with a coincidence measurement. The alpha particles penetrated through the carbon foils of the detector and then impacted on a silicon detector, which served as an event counter and provided the trigger signal to the data acquisition system (DAQ). To assess the relation between the detection efficiency and the energy of SEs impacting on the MCP of the time detector, we changed the SEs impacting energy by varying the electric field and the magnetic field simultaneously and then measured the detection efficiency correspondingly. These results are shown in Fig. 4(a). The detection efficiency increased with the SEs energy and reached the plateau of 61% for an energy higher than 400 eV, which corresponds to an electric field $\boldsymbol{E}$ of 120 V/mm and a magnetic field $\boldsymbol{B}$ of 0.0075 T.

3.2 Time resolution

To obtain the time resolution of the time detector, the other MCP is employed as a start time detector and also used as a trigger for measuring alpha particles instead of the silicon detector in Fig. 3. The time detector is used as a stop time detector for measuring secondary electrons emitted from the carbon foil. A collimator was located before the alpha source to reduce the flight path dispersion of the alpha particles. The time of flight between the time detector and the MCP used as start time detector was measured and the spectrum is shown in Fig. 4(b). The FWHM of the peak is 290 ps. This value includes the flight path dispersion of the alpha particles, the intrinsic time resolution of the start time detector and the time jitter of the electronics. By subtracting the contributions mentioned above, the intrinsic time resolution of the detector is about (197±10) ps (FWHM).

3.3 Vacuum

After 24 h baking at 150 ℃ in the vacuum chamber, a vacuum pressure of 6.4×10^{-11} mb was obtained, which meets the requirement of the ultra-high vacuum at CSRe.

4 Applications

This detector has been applied for mass measurement experiments at CSRe. The carbon foil of the detector was positioned in the circulating path of the stored ions. The secondary electrons emitted from the foil induced by circulation ions were guided isochronously to MCP. The signals from the detector were sampled with a digital oscilloscope Tektronix DPO 7254 at a sampling rate of 40 GHz and recorded for 200 μs for one injection, which are shown in Fig. 5. It's found in the ^{78}Kr fragment experiment that, the detection efficiency depends on Z of ions, as shown in Fig. 6(a). For the ions with higher charge, the more SEs emitted from carbon foil and then higher efficiency can be obtained. In general, the high energy ions induce less SEs than the low energy α particles used in the test, so the detection efficiency is generally lower. Meanwhile, some channels of the MCP will be blocked for a while after being hit by an electron directly, and the dead time of the channel is about several ms. This means that every channel can work only for one time for one injection. When too many ions are injected into CSRe in one time, the detection efficiency would be decreased because many channels will be blocked. In order to get high detection efficiency, the number of injected ions was kept under 20 for one injection during the experiment.

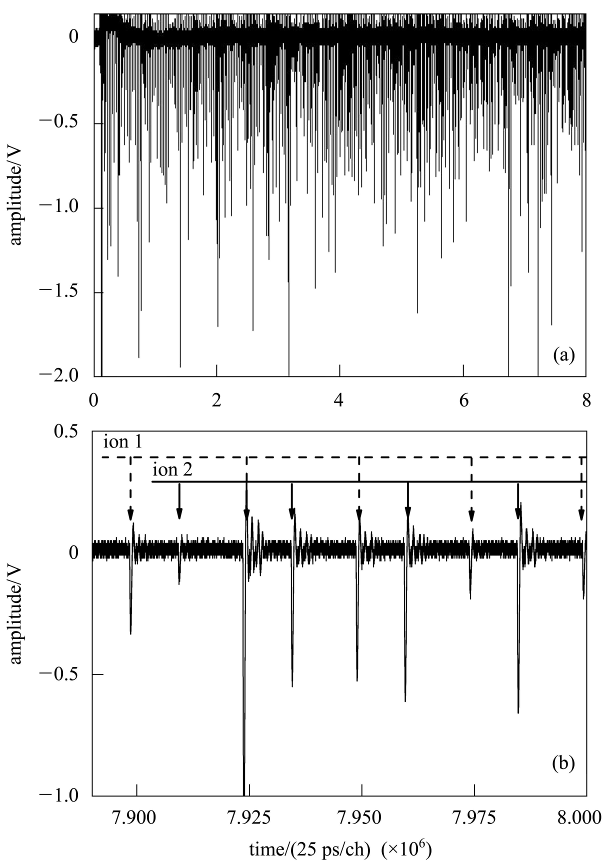


Fig. 5. (a) The signals were sampled with a digital oscilloscope Tektronix DPO 7254. (b) The enlarged one which shows two particles stored in the CSRe simultaneously.

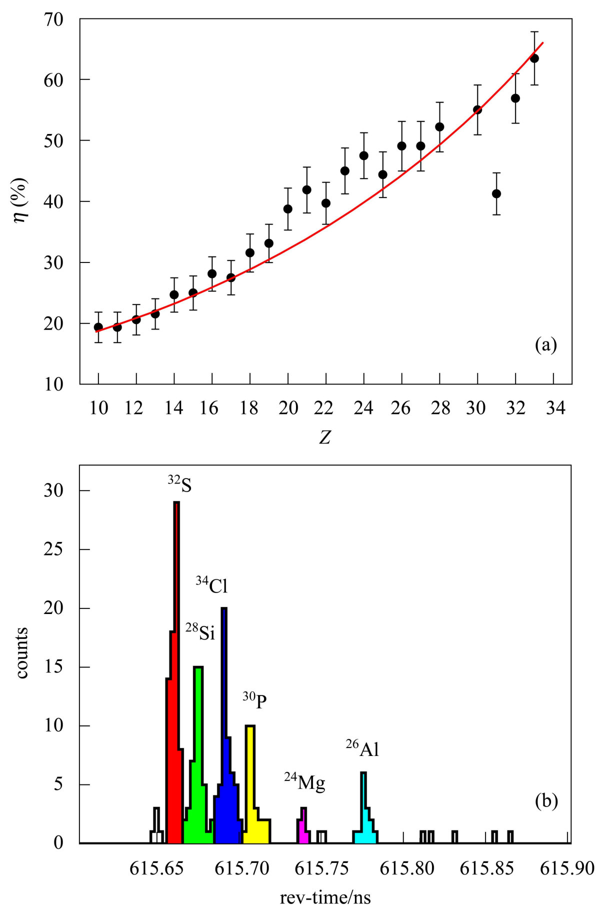


Fig. 6. (a) the detection efficiency depends on Z of ions. (b) The revolution time spectrum for all measured particles in the pilot experiment.

The arrival time information of each signal of each injection was determined with the constant fraction triggering technique. Then this time information was assigned to individual ions by utilizing the periodicity of their appearance. For each individual ion the revolution time was determined by a fit of these time informations as a function of the number of turns with polynomials. In order to minimize the effect of perturbations the revolution time was extracted from the slope at the first turn in a pilot experiment. The revolution time spectrum of mass measurements in a pilot experiment is shown in Fig. 6(b) [9], where the mass resolution around 8×10^{-6} for $\Delta m/m$ is achieved. The detector satisfies the requirement of mass measurements.

5 Summary

The time detector for mass measurements of short-lived nuclei at CSRe was designed and constructed. This detector is based on the SEs emitted when the ions pass a 20 μg/cm^2 carbon foil. The SEs are accelerated and bent by 180° in the crossed electric and magnetic fields, then transported isochronously to a multi-channel plate as an electron multiplier. A detection efficiency of 61% and a time resolution of (197±10) ps (FWHM) were obtained for ^{241}Am alpha particles. The 6.4×10^{-11} mbar of detector vacuum is suitable for the CSRe ultra-high vacuum. The detector has been used for mass measurements and a mass resolution of about 8×10^{-6} for $\Delta m/m$ is achieved. In order to get a higher performance, we will use a faster MCP and one carbon foil in the detector in the future.

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